Demonstration of Real-Time Modulation-Adaptable Transmitter

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Abstract *We demonstrate a 26 Gbaud real-time quick-reconfigurable 16QAM/QPSK-adaptable transmitter. The modulation format can be switched in less than a second by an RMAT agent. The FPGA-driven reconfigurable transmitter can work as a generic edge-node interface for traffic aggregation.*

Introduction

Elastic optical networks (EONs) promise a better network resource utilization by removing optical grid limitation existed in fixed-grid optical networks and adding flexibility in spectrum bandwidth allocation[1]. One of the key enabling technologies for EON applications is bandwidth variable transmitter (BVT), which could generate an optical signal with variable operation baud-rates to fill up bandwidth-flexible optical spectrum slots. Furthermore, BVT should also be capable of adapting the signal's modulation formats for different transmission reach. On the other hand, the emerged network convergence requires an edge-node interface to handle different traffics from either data centers, metro networks, or back-haul applications[2], and provide just-enough-bandwidth optical signals after traffic aggregation. In addition, quick reconfigurable optical transmitter is one of the key devices for instant network optimizaiton.

Thanks to the programmability and computing power of FPGA, a network function programmable node can be implemented by switching-over the internal FPGA functions through look-up tables[3]. The vast computing resource in FPGA could process and aggregate different network traffics for further transmission. A real-time baud-rate adaptable transmitter was demonstrated for optical transport network traffics[4]. However, to the best of authors' knowledge, modulation adaptability have not been demonstrated in real-time.

In this paper, we implement and demonstrate a real-time modulation-format adaptable transmitter (RMAT) based on a high-performance FPGA. The FPGA parses the incoming traffic and drives the modulation-adaptable transmitter. With a quick-reconfigurable auto-bias controller, the modulation-adaptable transmitter can switch its modulation format between 16QAM and QPSK in a second. Both the FPGA and the trasmitter are controlled by a local agent (RMAT agent) to adapt the optical signal modulation format. The modulation-adaptable transmitter can be potentially integrated with a SDN controller. A fully SDN-enable BVT can be used for network optimization in optical networks.

Generic Edge-Node Interface for network convergence

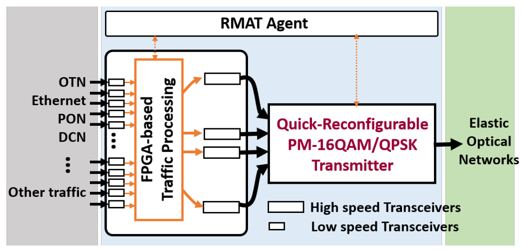

Fig. 1: Architecture of the generic edge-node interface

Figure 1 shows the architecture of the generic edge-node interface with the quick-reconfigurable transmitter. To provide the flexibility and the requests for future network convergence, the edge-node interface will take advantage of the huge IO resource and hardware programmability of FPGAs. Through low-speed transceivers, the FPGA could process the incoming traffic from OTN (Optical Transport Networks), Ethernet, access, data center and other networks. Then the FPGA could use its computing power to perform traffic parsing, protocol framing/mapping, traffic aggregation, and other operations. Then the processed traffic data will drive the BVT to generate optical signals for transmission towards EON. The capability to reconfigure modulation format could provide signals with flexible optical bandwidths and also accommodate the signals for different transmission distances. An RMAT agent controls both the FPGA and the transmitter to achieve the modulation-adaptability operation. The generic edge-node interface serves as an aggregating point to converge multiple network traffics to EON signal.

Experimental Setup of modulation-adaptable transmitter

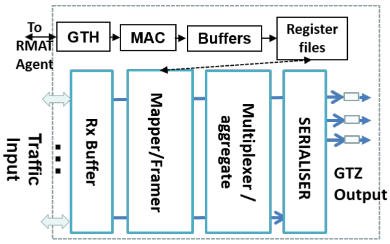

Fig. 2: FPGA function blocks for traffic processing and the RMAT Agent

The developed modulation-adaptable transmitter is implemented based on FPGA programmable electronic prototype (Xilinx virtex-7 580HT). With $23{\times}10.7$ Gbit/s high-speed transceivers (GTH), the generic edge-node interface can handle the incoming traffic over 240 Gbit/s. One GTH transceiver is used for RMAT agent to control the modulation format. After the internal FPGA processing, the traffic will be sent out through 2 serial high-speed transceivers (GTZ) with line rate up to 27 Gbit/s. The internal FPGA function blocks for traffic processing is shown in Fig.2. The GTH traffics are converted to up to 27 Gbit/s signals to further drive the modulation-adaptable transmitter. The internal block for modulation switchover control is also shown in Fig. 2.

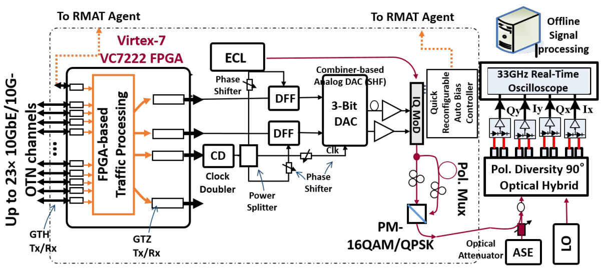

Fig. 3: Experimental setup of real-time modulation-adaptable transmitter

Figure 3 shows the experimental setup of the implemented real-time modulation-adaptable transmitter. Three serial GTZ transmitters drive the modulation-adaptable transmitter. Among these, two GTZ transceivers handle the data, while another GTZ provides a half clock, which is doubled by a clock doubler (CD) to synchronize two digital flip-flops (DFF) and a 3-Bit DAC. The DFFs are used to improve the signal quality. After regeneration, two data streams are sent to a 3-Bit DAC (from SHF) to obtain multiple level signals. The 3-bit DAC is an analog device based on power combiners, which could provide wide bandwidth and high signal quality with precise phase match. In the current setup, we only use 2 bits for the transmitter.

Figure 4 shows the operation principle for the modulation adaptability. The modulation adaptability is achieved by reconfiguring the driving signals. As shown in Fig. 4 (a), two independent data streams after the 3-Bit will generate 4-level signals. The electrical eye diagram of the 4-level signal is measured with a 50 GHz oscilloscope and shown in the insets of Fig. 4. Then the 4-level signal will drive an IQ modulator and 16QAM signals can be generated. For the QPSK signal generation, two identity signals will be sent out from two GTZ transceivers. After the combination in the 3-Bit DAC, only two level signals can be generated with a maximum amplitude. Then the generated 2-level signals drive the IQ modulator to generate QPSK signals. Based on this principle, the optical modulation can be programmable by manipulating the data of the two GTZ transmitters on the FGPA. Figure 4(c) show the captured message of RMAT agent communicating with the FPGA. The internal function switchover time of the FPGA is about several μs. However, these two different modulation formats require the IQ modulator biased at different operation points. Thus, another challenge for quick modulation reconfigurable is the auto bias control. In our demonstration, a reconfigurable bias controller stored two sets of parameters for two different bias states and provide a quick switch between the two states. With the developed RMAT controller, both the FPGA and the bias controller could reconfigure the modulation format quickly. The transmitter can be potentially integrated with SDN controller.

Experiments and Discussion

As shown in Fig. 3, the generic edge-node interface with RMAT is characterized with a polarization-diversity coherent receiver. The modulation-adaptable transmitter generates 26Gbaud PM-QPSK/16QAM signals. The operation baudrate is limited by the used clock doubler with a maximum bandwidth of 26GHz.Then an 80 Gs/s four-channel real-time oscilloscope with a bandwidth about 33 GHz sampled the electronic signals to digital signals for further digital signal processing. The offline processing performs normalization, polarization de-multiplexing, frequency offset compensation, carrier phase estimation, and LMS filter for performance optimization. Then symbol detection and bit-error ratio counting are followed for the performance test.

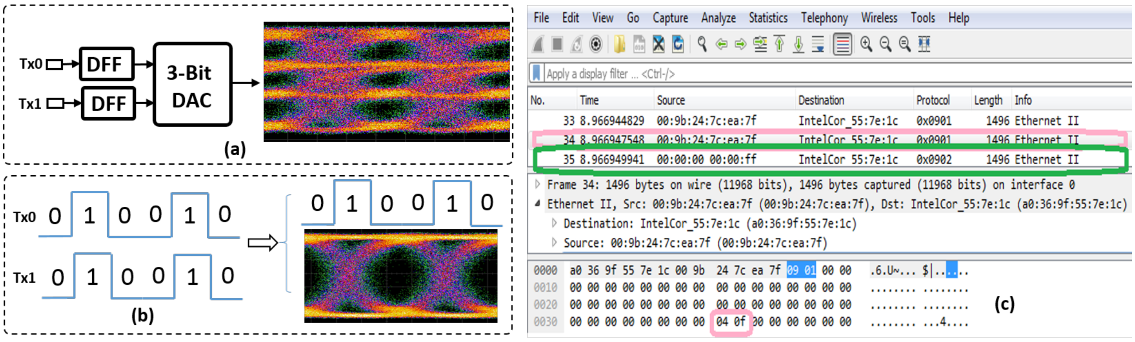

Fig. 4: Principle of modulation adaptability: (a) 4-level drive signal generation with two independent data; (b) 2-level drive signal generation with two identical data;(c) Captured message for communication between RMAT agent and FGPA

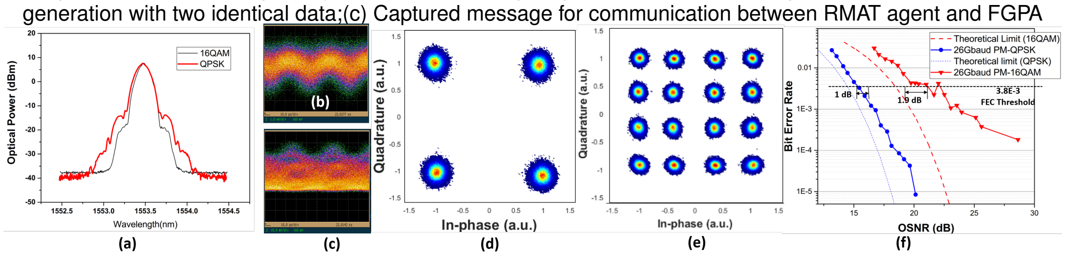

Fig. 5: (a) Spectra of the generated 26 Gbaud QPSK/16QAM signal; (b) Eye diagram of the QPSK signal; (c) Eye diagram of the 16QAM signal;Recovered constellation distributions for (d) QPSK and (e) 16QAM ; (f) BER vs. OSNR performance test

Figure 5(a) shows the measured spectra of both PM-16QAM and PM-QPSK signals. The spectrum of the PM-16QAM signal shows low side lopes than that of the PM-QPSK signal, due to the relatively low voltage of the 4-level signals. The corresponding electric eye diagrams for both QPSK and 16QAM signals are shown in Fig.5 (b) and (c). The noisy eye diagram is partly due to the used out-dated oscilloscope with bandwidth less than 50 GHz.

The received signal distributions are shown in Fig.5 (d) and (e) for PM-QPSK and PM-16QAM signals. Assisted by two DFFs, the output signals of the FPGA serial transmitters are improved a lot, and lead to high-quality signals. By adding extra ASE noise to the signal, we tested the OSNR vs. BER curve and showed the results in Fig.5 (f). The required OSNR to achieve BER = 3.8E-3 (7% FEC threshold) is about 20.3 dB and 15.36 dB for PM-16QAM and PM-QPSK signals. Regarding quick reconfiguration of modulation format, we use optical spectra as an indicator for stable bias controlling. The auto-bias controller recorded two sets of the bias parameters for both QPSK and 16QAM, thus the corresponding parameters can be retrieved in advance. Without the locking time, the bias controller can switch its operation status quickly. The auto-bias controller is aslo controlled by the developed RMAT agent. The captured agent communication messages in Fig. 4(c) confirmed the RMAT agent configures the modulation-adaptable transmitter successfully. Including the switching time of the bias controller, the preliminary test shows the modulation adaptability can be performed in less than one second.

Conclusion

A 26 Gbaud FPGA-driven real-time modulation-adaptable transmitter is demonstrated real-time successfully. A local RMAT agent configures both the auto bias-control board and FPGA to reconfigure the modulation in less than one second with stable outputs. The FPGA-based modulation-adaptable transmitter provides both network function programming and optical signal flexibility, which can work as a generic edge-node interface for elastic optical networks. The instant modulation-adaptability could be used for real-time optical network optimization.

Acknowledgments

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